2002-03

An analysis of the transition of the Objective Individual Combat Weapon (OICW) from advanced technology demonstration to acquisition program

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THESIS

AN ANALYSIS OF THE TRANSITION OF THE OBJECTIVE INDIVIDUAL COMBAT WEAPON (OICW) FROM ADVANCED TECHNOLOGY DEMONSTRATION TO ACQUISITION PROGRAM

by

Erik C. Webb

March 2002

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2002	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: An Analysis of the Transition of the Objective Individual Combat Weapon From Advanced Technology Demonstration to Acquisition Program			**5. FUNDING NUMBERS**
6. AUTHOR(S) Erik C. Webb			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release, distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT *(maximum 200 words)*

The OICW is envisioned to be a lightweight, shoulder-fired weapon having a dual munitions capability and an advanced day/night fire control. The OICW is expected to provide substantial improvements in lethality over the predecessor rifle and carbine families of weapons. The Office of the Program Manager for Small Arms assessed the OICW Advanced Technology Demonstration process and program progress in 1998 and concluded the ATD process did not accomplish/address the actions that are necessary prior to entering engineering and manufacturing development. This thesis examines how the ATD process could be improved to better improve similar, subsequent weapon systems from inculcating risk that endangers the program.

14. SUBJECT TERMS Objective Individual Combat Weapon, Small Arms, Advanced Technology Demonstration, Weapons Acquisition, Best Practices			**15. NUMBER OF PAGES** 67
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN MANAGEMENT

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ABSTRACT

The Objective Individual Combat Weapon (OICW) will replace selected M16 rifles and M4 Carbines in combat and combat support organizations in the U. S. Army. The OICW is envisioned to be a lightweight, shoulder-fired weapon having a dual munitions capability and an advanced day/night fire control. The OICW is expected to provide substantial improvements in lethality over the predecessor rifle and carbine families of weapons. The Office of the Program Manager for Small Arms assessed the OICW Advanced Technology Demonstration (ATD) Process and program progress in 1998 and concluded that the process did not prepare the program for Engineering and Manufacturing Development (EMD) as originally planned and that the ATD exit criteria and the Operational Requirements Document threshold requirements were too far apart to allow entrance into EMD. Despite the decision to transition the program to Program Definition and Risk Reduction, the ATD process did not accomplish the actions that were necessary to reduce cost, schedule and performance risk to the program. This thesis examines how the acquisition process could be improved to better improve subsequent weapon systems from inculcating risk that endangers the program.

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I. INTRODUCTION

> [The] OICW failed to meet key effectiveness and suitability ATD exit criteria in Government testing during the fall of 1999. The most important of these criteria were probability of incapacitation (Pi), weight, and safety. These three areas are considered high risk and will require aggressive risk reduction measures during the Program Definition Risk Reduction (PDRR) phase [SER 2000].

A. PURPOSE

The purpose of this research is to examine the efficacy of the OICW ATD in preparing the system for transition to an acquisition program. The goal is to provide an analysis and lessons learned of the ATD approach to developing technologically advanced weapon systems and transition to program management.

B. SCOPE AND METHODOLOGY

The scope of this research is limited to include: (1) A review of U.S. infantry weapons procurement leading to the OICW, (2) a review of the requirements for the system, (3) a review of the technology transfer mechanisms used to initiate programs and (4) an analysis of the OICW ATD effectiveness compared to commercial and business practices for research and development of new technology and corresponding lessons learned. The research is limited to addressing the system's Operational Requirements Document's Key Performance Parameters.

The thesis uses a case study methodology. This research topic is concerned with the processes of managing a weapon system program incorporating significant technology. By examining key aspects of this acquisition program within the context of DoD acquisition practices, and comparing those practices to the commercial sector's we may elicit lessons as to why the OICW ATD has been characterized as failing in its goal to prepare the system for transition to an acquisition program.

C. RESEARCH QUESTION

What processes could have been implemented to improve the ATD-to-PMO transition for the OICW?

Subsidiary questions:

What is the background of the OICW system and why is it required?

What are the requirements for the system?

What is the purpose of an Advanced Technology Demonstration?

What are the challenges and issues in ATD transition to PMO?

How effective was the ATD in developing the OICW for transition?

What lessons learned are applicable to this study?

D. METHODOLOGY

The methodology consisted of conducting a literature search of books, journal articles, and library information resources on the history of small arms development in the U.S. To provide an understanding of the need for the OICW, I conducted a thorough review including, but not limited to: user requirements for the system, the acquisition strategy, the contract with the prime integrator, the System Evaluation Report issued by the Army Test and Evaluation Command and the Joint Service Small Arms Plan. To demonstrate the processes of technology transfer, I conducted a review of the ATD process and the specific ATD for the OICW. To demonstrate the issues surrounding the transition from ATD to program, I compared lessons learned from previous weapon system programs, as summarized in GAO reports, to the expected outcome of the OICW program.

E. ORGANIZATION

The thesis is divided into five chapters:

Chapter II provides a background of small arms development in the U.S. to demonstrate common themes with the OICW program.

Chapter III identifies and discusses problems and issues involved with the OICW ATD and parallels with other weapon system development programs.

Chapter IV provides an analysis of the ATD transition and presents lessons learned based on a comparison of business practices in the development of, and integration of new technology from previous weapon system programs.

Chapter V presents conclusions and recommendations based on lessons learned that are applicable to the OICW and future objective weapon programs.

F. EXPECTED BENEFITS OF THIS THESIS

This thesis identifies lessons learned from the OICW program and other weapon system programs. These lessons learned will assist program managers, by demonstrating measures to identify risk through timely insertion of technology into weapon system programs. Ultimately, this information may lead to weapon programs that espouse less risk and enjoy reduced development time.

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II. BACKGROUND--HISTORY OF SMALL ARMS DEVELOPMENT LEADING TO THE OICW

A. INFANTRY RIFLE PROCUREMENT FROM 1946

> Since the end of World War II, the United States Army has been seeking a better infantry weapon. The quest for a new rifle has often been filled with frustrations and failures. As a consequence of unrealistic military requirements, poor management, disputes within NATO, and congressional stinginess, it took twelve years to develop and replacement for the M1 rifle. [EZELL 1984]

B. LIGHTWEIGHT RIFLE PROGRAM

The M14 rifle was the product of the lightweight rifle (LWR) program and replaced the M1 as the infantryman's primary weapon. The LWR program (1945-1961) was marked by an absence of a sense of urgency and emphasis. As a result in manufacturing problems, delays, and the failure of the weapons design in controlled automatic fire, the Department of Defense (DoD) ceased funding production of the M14 in 1962.

C. SPECIAL PURPOSE INDIVIDUAL RIFLE PROGRAM

In 1963, the DoD announced the purchase of the AR15 as an interim measure. Meanwhile, the follow-on to the LWR was the Special Purpose Individual Weapon (SPIW) program. This effort pursued the possibility of a small caliber "flechette"[1] round for use in a military rifle. After extensive development and testing, no SPIW prototypes could attain reliability, durability and weight requirements. In 1966, the Army

Figure 2-1, Prototype SPIWS

From top: Springfield Armory, AAI Corp (2) [After Ezell 1984]

[1] Flechette- a projectile fired from a rifle in the form of a thin, lightweight, fin-stabilized steel dart.

Chief of Staff announced the M16 would be adopted as the standard infantry rifle and the SPIW program was to become part of a wider R&D effort to develop a follow-on weapon to the M16.

The AR15/M16 was a departure from the historic method of rifle development in the United States since 1794—it was the first completely commercial rifle research and development (R&D) venture adopted by the services. [EZELL 1984] This newer weapon was rushed through the testing and evaluation process so that it could be placed in the hands of troops fighting in Vietnam. The rifle's appeal was due to the same features sought after in the lightweight rifle program—lightweight, controllable at full automatic fire, short length, accurate and effective. However, as a result of hurried development, and the hasty and inadequate training provided to deployed troops, life threatening malfunctions emerged, lending a poor reputation to the rifle.

Due to the perceived inadequacies of the M16, the Army developed improvements to the design that addressed the concerns of troops in the field. This led to the improved M16A1 rifle. The changes included enhancements to improve reliability. Although the standard infantry weapon, the M16 was still essentially an interim weapon.

> By 1970, other NATO countries were beginning to make noises about standardizing a new rifle caliber cartridge. Placed in a position of defending the 5.56mm cartridge, the United States military was not yet ready to propose a type of ammunition as radical as the flechette round[2]. One Defense official expressed a more cynical view. He stated that "the SPIW program, unfortunately, was not a weapon; it was a political tactic to head off possible major purchases of the M16. [EZELL 1984]

The decade between 1973 and 1983 saw little in the way of progress towards the development of a new infantry weapon. The U.S. Army Combat Developments Command issued a materiel need document (MND) for a future rifle system to allow a 25% increase in effectiveness over the current M16A1. The program was based on a concept of firing multiple projectiles from a single cartridge. This program failed to

[2] In the late 1950s, the U.S. defeated a British attempt to standardize infantry cartridges around a well-developed 7mm medium power cartridge, claiming is diminutive aspects not suited to U.S. infantry requirements. At the time the T25 and T44 development rifles (precursors to the M14) were in development in the U.S. and both were designed around a full power 7.62mm cartridge. NATO countries dropped the medium cartridge effort and soon followed suit, adopting the 7.62mm cartridge. After the demise of the M14 program, the U.S. defaulted to a 5.56mm cartridge, even smaller than the original British suggestion. This put the U.S. in an awkward position having now adopted the M16 as the "standard".

develop a reliable product that met requirements. As with the SPIW program, the future rifle system's MND was rescinded and the R&D activities were reoriented to examine conceptual approaches to the development of new technology for future small arms systems.

Concurrently and as a result of NATO munitions standardization, requirements developed by the Marine Corps and the United States Army Infantry Center, Ft Benning, GA (USAIC) led to the development of the M16A2. M16A2 improvements included a redesigned barrel to support firing a heavier projectile, improved sights and integral provisions for left-handed firers. Due to munitions and weapon enhancements, the rifle's range increased to 800 meters from 300 meters.

Figure 2-2 Prototype ACRs

From Top: AAI Corp, Colt Ind., Heckler and Koch [After Hogg as cited in Velleux, 2001]

D. ADVANCED COMBAT RIFLE PROGRAM

In 1984, the Army instituted the advanced combat rifle (ACR) program. This research effort was a technology search to incorporate improved sighting systems, multiple projectile rounds, and use of caseless ammunition.[3] The ACR program developed several weapon prototypes, none of which where appreciably better than the M16A2 in testing.

E. OBJECTIVE INDIVIDUAL COMBAT WEAPON PROGRAM

The OICW program was instituted in 1994 after the Advanced Combat Rifle program failed to produce a next generation rifle that was appreciably improved over the existing M16A2. [CUTSHAW 2000]

[3] Caseless ammunition does not use a metallic cartridge case to contain propellant.

The OICW will be a dual weapon system that combines air-bursting munitions, secondary kinetic energy munitions, a full solution fire control (that contains a laser range finder with beam steering, computer, thermal, TV and direct view optics modes, environmental sensors, electronic compass with vertical angle measurement, target tracker, combat identification, and a laser pointer to affect decisively violent and suppressive target effects. It will include embedded/appended training and embedded diagnostics, and be interoperable with Land Warrior [TEMP 2000].

After having completed the Concept Exploration (CE) phase in 1999 concluding in an Advanced Technology Demonstration (ATD) of engineering prototypes, the OICW is now in the Program Definition and Risk Reduction (PDRR) phase of the program.

The Office the PM Small Arms (OPMSA) awarded a contract to Alliant TechSystems (ATK) for the PDRR phase of the OICW program. The purpose of this phase was to develop a near-final system design that will enable the Product Manager (PM) Small Arms to enter into Engineering and Manufacturing Development (EMD) with acceptable risk of meeting the required system performance, cost and schedule.

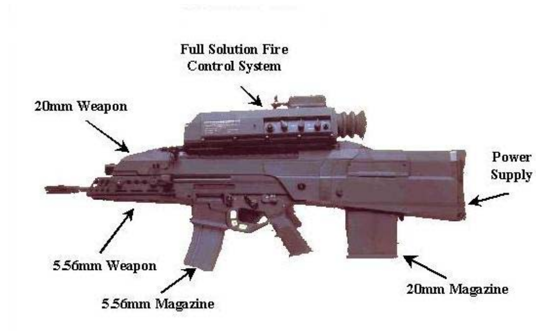

Figure 2-3, An ATD prototype OICW

F. TECHNOLOGY TRANSITION MECHANISMS

The Army's goal for science and technology (S&T) is to demonstrate timely and affordable weapon system concepts through Government and private industry to maintain land warfare supremacy. The Army's vision for S&T is the "early retirement of risk in materiel development programs" [DA Pam 70-3, 1988]

The transition point from the demonstration of technology into a formal acquisition program for a new system occurs at Milestone I when a program begins the PDRR phase. This occurs after a validated need has been approved at Milestone 0, and ideally, when technologies critical to performance have been proven. This action requires coordination of the S&T developer, the systems manager (User representative)/PM (MATDEV), and the combat developer (CBTDEV). Prior to transition from S&T, the following criteria must be met:

- The technologies have been demonstrated, thoroughly tested, and shown to be predicable.
- There is a clear and verified military need for the new capability system or system upgrade.
- The new capability system is cost effective.

1. The Advanced Technology Demonstration

An Advanced Technology Demonstration (ATD) brings the CBTDEV, MATDEV, and industry together to explore the technical feasibility, affordability, and potential of technologies to support current and emerging warfighting concepts [DA Pam 70-3].

ATDs help speed the introduction of advanced technologies needed to develop future systems and allow experimentation with technology-driven operational issues. The goal is to provide a better understanding of capabilities versus technology, resulting in a more informed requirements document prior to a Milestone I decision. ATDs allow exploration of technical options and the elimination of unattainable technologies in the early stages of a program. This process is accomplished through an Integrated Product/Process Development (IPPD) approach. ATDs ensure a higher probability of success when technology is transitioned to a formal acquisition program. The ATD process is depicted in Figure 2-5.

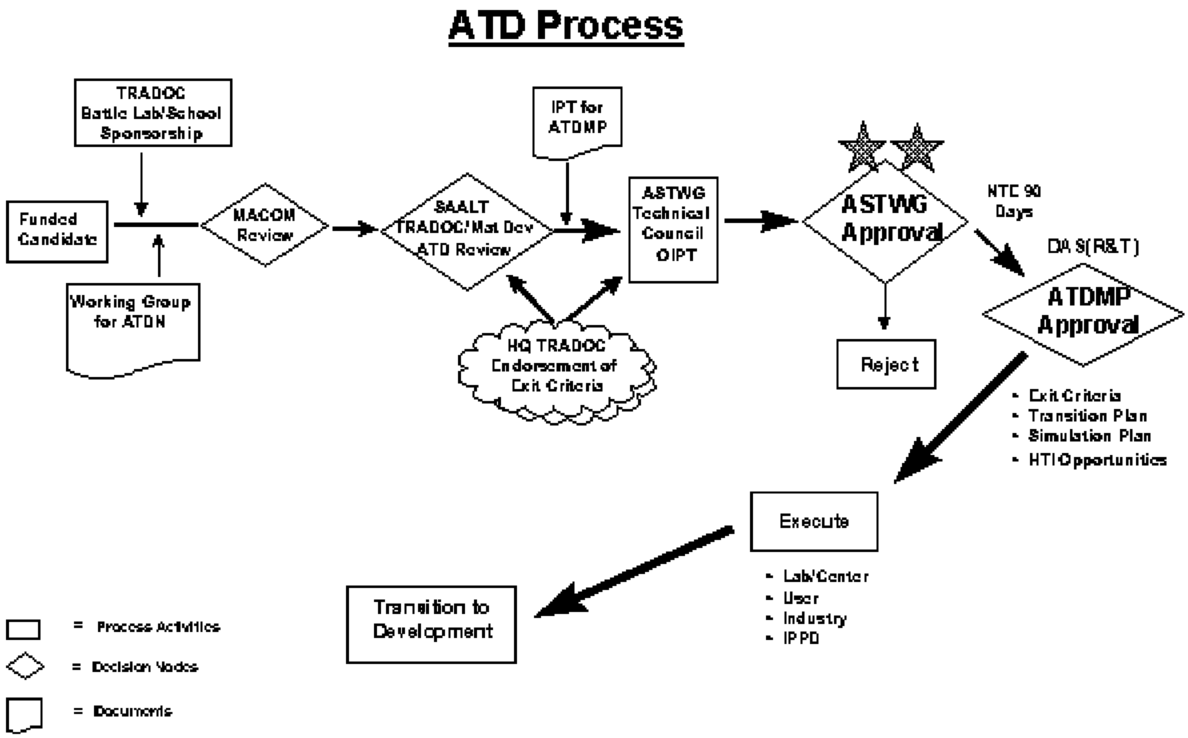

Figure 2-4, ATD Process

From DA Pam 70-3, Research, Development, and Acquisition -- Army Acquisition Procedures

2. Advanced Concept Technology Demonstration

> An Advanced Concept Technology Demonstration (ACTD) evaluates the military value of advanced technologies through a large-scale experiment with an operational unit while ATDs evaluate technical performance in conjunction with a TRADOC Battle Lab or Center [DA Pam 70-3].

ACTDs are DoD sponsored programs to assess the utility of near-term, technology solutions that are ready to be fielded to operational organizations. These solutions must address a military need validated by the Joint Requirements Oversight Council (JROC). ACTDs develop the concept of operations that is needed for effective use of these solutions. ACTDs provide residual equipment that is issued to an operational unit for a two-year extended user evaluation (EUE) period after a field demonstration. At the end of the evaluation period, a decision is made whether or not to proceed with acquisition based on the results of the assessment and, ultimately, on prioritization by service leadership.

The goal of technology transition mechanisms is to demonstrate timely and affordable weapon system concepts to maintain land warfare supremacy by eliminating or reducing risk early in an acquisition program.

G. SUMMARY

A common theme in infantry weapon procurement through the OICW is the concept of appending the soldier with a means to deliver projectiles--accurately. Each succeeding program attempted to infuse current technology to produce a weapon with greater capability than the last. Where the OICW program departs this paradigm is the integration of the system. Instead of developing and fielding adjunct equipment to hang on a rifle, the OICW program intends to integrate all of the devices and technology that currently requires an infantryman to carry up to 22 pounds of equipment, incidental to his rifle. Comparing the recent history of infantry weapons programs, the OICW would appear to have many of the same risks in development as its predecessors (namely developing a reliable weapon that meets requirements). In many of the historical examples, the management of adoption of immature technology into weapon programs led to disappointing test results and performance.

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III. DATA

A. RESEARCH FOCUS AND APPROACH

The focus of the research is limited to literature published as a result of the OICW program, both by Government and non-Government organizations and non-structured interviews with people involved with system development. Research included articles published by defense review firms, independent small arms policy analysis organizations and service component program management, combat developer and user representative elements.

This is a case analysis of the management functions in transfer of an acquisition category-two (ACAT II)[4] weapon system from the technology base to a formal acquisition program. The analysis focuses on the mechanisms to help determine when technology is sufficiently mature to be included in an acquisition program.

The information required to analyze exists in periodicals, Government publications and the comments of the acquisition team involved in the development of the OICW. I chose an unstructured conversational questionnaire approach to individuals involved in the acquisition of the system. Additionally, I conducted a periodical search to garner additional information that would allow analysis to determine if the ATD process poised the OICW program for success as an acquisition program.

The research and analysis is limited to address four of the system's Operational Requirements Document's Key Performance Parameters (KPPs) to limit the study to a manageable scope. An analysis of the KPPs of weight, lethality, firing position and system lethality provides sufficient information to draw conclusions that may be applied to other objective weapons programs.

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[4] A categorization of a program under $140 million in research, test, development and evaluation or under $645 million in procurement costs

B. CHALLENGES AND ISSUES IN THE TRANSITION FROM ATD TO ACQUISITION PROGRAM

The goal of an ATD is to mature technology for inclusion in weapon systems and eliminate unattainable technologies in the early stages of development. In order to provide for the success of the OICW ATD transition, exit criteria were developed to evaluate the maturity of technologies used in the development of the prototype weapons. The ATD provided a prototype weapon that met requirements in several areas. The prototype weapon demonstrated the ability of the TA/FCS to program the 20mm ammunition to detonate at a specified range. The weapon additionally demonstrated the direct view portion of the TA/FCS system coupled with a laser rangefinder and target aim points. And importantly, the weapon system demonstrated the validity of the concept to engage enemy targets at standoff ranges in defilade positions. However, four key performance characteristics fell short of meeting criteria supporting program transition. The OICW critical aspects of weight, lethality, target acquisition and firing positions did not meet ATD exit criteria goals. The following data provide indicators to the maturity level of the technology incorporated in the OICW ATD. The importance of this data is to provide a basis to assess the relative technology maturity and analyze the possible linkage between technology maturity and risk of program failure. How does one know when a technology is ready for inclusion into a weapon or product?

1. Technology Readiness Levels

The National Aeronautics and Space Administration (NASA) and the Air Force Research Laboratory (AFRL) use technology readiness levels (TRLs) to determine the maturity of technologies to be incorporated into systems. Readiness levels are measured on a scale of one to nine, beginning with paper studies of the basic concept, proceeding with laboratory demonstrations, and culminating with a technology that has proven itself on the intended product.

TRL	Technological Characteristics
9	Actual system “flight proven” through successful mission operations
8	Actual system completed and “flight qualified” through test and demonstration
7	System prototype demonstration in an operational environment
6	System/subsystem modes or prototype demonstration in a relevant environment
5	Component and/or breadboard validation in a relevant environment
4	Component and/or breadboard validation in a laboratory environment
3	Analytical and experimental critical function and/or characteristic proof of concept
2	Formulation of technology or application
1	Basic principles observed and reported

Table 3-1, Technology Readiness Levels (TRLs)
After GAO NSIAD 99-162

The data presented will lead to a subjective, relative TRL rating based on the demonstrated ability of the technology to meet requirements. Distilling the effectiveness of OICW system components based on ability to meet exit criteria and user requirements into a guide number, or TRL, will provide insight into the effectiveness of the ATD in preparing the weapon system and program office for a successful transition from the technology base.

2. Problem One--Weight

The infantryman is charged with the mission to close with and defeat or destroy enemy forces through dismounted maneuver (fires and movement) in order to control terrain or other specific objectives. This requires the infantryman to carry the means to exact violence on his opponents. Quick and agile maneuver in close terrain require the soldier to move unencumbered. A lightweight, effective weapon is essential to the infantryman in order to accomplish his mission. A weapon that is too unwieldy or heavy will hinder a soldier’s ability to quickly bring his weapon to bear on the threat and inhibit reflexive firing in close terrain. The major issue in weapon weight is portability, the ability of the individual to transport the weapon from location to location without undue stress and fatigue. Forces operating in dismounted battlespace require the capability for rapid, agile maneuver in close terrain, vehicular restrictive terrain, and during airborne, air assault, and waterborne operations [TRADOC Pamphlet 525-66].

The theoretical advantage of the OICW is the integration of many performance-enhancing subsystems into one platform for the soldier. Whether the components are integrated into a single system or provided piecemeal and carried in-hand and in a rucksack, the soldier still must carry them on the mission to have them available. Currently, the M4 carbine or M16 modular weapon system, with all of its attachments weighs approximately 19.5 pounds. The prototype (ATD) OICW weighed 21.08 pounds without direct view optics, television, laser designator, Multiple Integrated Laser Engagement System (MILES)[5] laser and other TA/FCS components [SER 2000]. A carrying sling would usually transfer the load from in-hand weight to the shoulder-neck area, but in-hand carry is frequently needed in combat situations to engage opponents, negotiate rough terrain or obstacles. It is essential for combat effectiveness and survivability to be able to maneuver quickly with minimal physical stress with a lightweight, effective weapon.

The threshold weight requirement for the OICW is less than 14 pounds when fully loaded with primary [8 high explosive (HE)] and secondary [30 kinetic energy (KE)] cartridges, full solution day/night target acquisition/fire control system (TA/FCS), power supply and sling. However, the objective weight, the weight the combat developer would prefer the system weigh, is less than 10 pounds [ORD 2000]. It is intuitive that overall weapon weight reduction will improve soldier performance.

For the ATD, the system failed to achieve its 19.9 pound loaded weight requirement by half of a pound. However, since the ORD was approved after the ATD exit criteria were established, a better approximation of the ATD achieved weight with the correct ammunition load and other weapon sight components would be approximately 21.08 pounds.

---

[5] MILES is a training engagement system that uses a sound activated laser attached to a weapon to simulate the effects of firing.

> The technology demonstrators that underwent troop trials at Aberdeen Proving Grounds, MD weighed over 8kg (17.6 pounds). The goal was to have the fielded version of the OICW weigh just over 6kg (13.2 pounds), but either figure is substantially heavier than the M16A2. Again, however, this must be balanced against the weight of an M16A2 with M203 and night vision optics, which is approximately the same [Cutshaw 2000].
>
> Integration of the thermal sight, direct view optics, television camera, laser rangefinder, sight reticule, fire control system, sensors, compass, combat identification system, laser illuminator/pointer, force on force laser and embedded training into a lightweight, rugged sight is an extraordinary technical challenge [SER 2000].

During the ATD, the OICW possessed only the laser rangefinder, direct view optics, fire control and reticule. Even with the limited functionality, the prototypes suffered from reliability and performance problems [SER 2000]. Incorporation of required functions are anticipated to add to the weight issue.

The prototype OICW used in the ATD included weight reduction measures such as fire control housing made of beryllium, a 20mm grenade launcher barrel made with a titanium sleeve, a 5.56mm barrel that is two inches shorter than that of the current M4 carbine barrel, and lightweight components used in the weapon body. These materiel alternatives to achieve weight goals increased costs through complexities in fabrication and increased cost over conventional materials. The use of such materials can increase program cost and performance risk

3. Problem Two--Firing Positions

The OICW is required to be effective from the standing, crouching, kneeling, sitting, prone and foxhole (standing supported) positions. The ATD testing did not address the firing position parameter. Since the ATD was a test of prototypes, a finding would likely be moot since the ATD weapon may not be physically representative of the production weapon. Proper use of differing firing positions based on terrain and the threat enables the firer to see the target and maximize the probability of hit [P(h)]. Proper firing positions provide stability and minimize aiming error. Not all fires can be performed from a supported position, the most stable firing position. At times, vegetation or obstacles may block the line of sight from these positions, especially in an assault where fields of fire cannot be prepared. The OICW prototypes that were tested by Army Research Lab (ARL) at Aberdeen Test Center (ATC) had limited capabilities [SER 2000]. Additionally, the weapons were fired from only the kneeling supported position. This limited the ability to assess whether there is any degradation in performance when fired from prone, sitting or standing positions required by the ORD. However, the soldiers participating in the test events provided some information from the human factors questionnaires.

A human factors engineering (HFE) questionnaire administered to the 12 soldiers involved in the OICW testing. One of the HFE issues that merit increased analysis was the potential for problems with the 20mm ammunition magazine when firing from the prone, sitting and standing positions. The 20mm weapon is a bullpup[6] configuration. This means that the construction of the weapon has the firing hand forward of the action and ammunition supply. When posed with the question whether the location of the 20mm magazine posed any problems in firing under field conditions, 10 of the 12 respondents answered yes. Particular answers included concerns over striking the 20mm magazine when executing individual movement techniques (low/high crawl, conduct of short rushes). Six of 12 respondents commented that weight, size and awkwardness of the prototype weapons were the worst features of the OICW. Since the weapons tested were prototypes with likely physical configuration changes in the future, further testing and analysis are required to fully answer the requirement. Despite the prototype designation of the ATD OICW, the results of the HFE questionnaire administered to the test participants demonstrate that factors of magazine location coupled with weight and awkwardness infer firing from positions other than kneeling supported may be compromised. Aggravating factors in maintaining a steady hold in realistic conditions can increase errors in engaging targets.

[6] A rifle in a bullpup configuration places the grip and firing hand forward of the chamber and ammunition supply. This configuration allows for the weapon to maintain the same barrel length as a conventional rifle, but with a shorter overall length.

4. Problem Three--Range/Lethality

Errors inherent in weapons that propel projectiles are categorized by interior, exterior and terminal ballistic variability. Factors that must be considered in determining effectiveness include: range-to-target error, aiming error, round-to-round dispersion error, munitions detonation error and lethal radius or terminal effects error. These errors must remain individually miniscule in order for the series of ballistic events to be effective, that is to be consistently accurate.

Determining the effectiveness of a weapon system is difficult. There is no current methodology to directly measure the probability of incapacitation of enemy personnel based on testing. During the ATD, Point exposed target P(i) was measured using two Army Material System Analysis Activity (AMSAA) models. The tests included the soldier's ability to accurately determine the range to a target with a laser rangefinder, the soldier's ability to accurately aim the weapon, measurement of the munitions' ballistic performance, and the measurements of the bursting munitions at the point of detonation.

Although the bursting radius of 20mm munitions for the OICW are classified, the accuracy in delivering an explosive round to the target may be used as a surrogate to help determine the effectiveness of the system. The OICW 20mm ammunition is required to provide a threshold probability of incapacitation [P(i)] of 0.50 day or night from the minimum arming distance to 500 meters. The purpose behind this requirement is to allow the soldier to engage enemy personnel from a standoff position, beyond effective range of most assault rifles.

> The technological goal for the high explosive air burst (HEAB) system is a P(i)/s = 0.50 against the described target. Sensitivity analysis shows tremendous gains in force effectiveness up to a P(i)/s = 0.50 and little significance beyond. A P(i)/s = 0.50 allows a single soldier equipped with OICW to defeat a 9 man threat squad with a minimum of ammunition - 18 rounds (9 / 0.50) [ORD 2000].

A P(i) of 0.50 and a combat load of 40-20mm rounds would allow the OICW equipped soldier the capability to defeat 9 exposed, protected targets and engage in a second fight without resupply [ORD 2000]. A P(i) of 0.50 reduces ammunition basic load and reduces resupply requirements. The objective requirement is for the system to provide a P(i) of 0.90 from minimum arming distance to 750 meters.

> The grenade itself is a product of modern miniaturization technology and incorporates not only programming from the fire-control system, but a revolution counter to determine range for an airburst. Lethal radius of the grenade is claimed to be approximately 3m [Cutshaw 2000].

The lethal radius (where the P(i) is .50) did not meet requirements for point, exposed targets. A significant factor in P(i) is accuracy and the process of determining the correct range to the target. Error in relation to the bursting radius of 20mm munitions to the target is the result of several factors: Range estimation errors [including environmental effects such as obscurants (dust, fog and snow) wind and mirage effects due to thermal differentiation,] soldier aim error, round to round dispersion, round detonation variability and variability in lethal effect of each round. Range estimation errors resulting from the ATD for a stationary, exposed target was 6.6 meters.

In order to attain larger burst areas per round, micro-electro-mechanical systems (MEMS) may be required to enable larger amounts of energetic material to take the place of current safe, arm and fusing mechanisms. MEMS are the integration of mechanical elements, sensors, actuators, and electronics on a silicon wafer through the micro fabrication technology.

Microelectronics are fabricated using integrated circuit (IC) processes and micro - mechanical components are fabricated using machining processes that selectively etch away parts of a silicon wafer or add new structural layers to form the mechanical and electromechanical devices. To meet requirements for lethality, technology is in a rather immature state for micro mechanical safe and arming mechanisms and MEMS used in airburst small arms munitions [JSSAP 2001].

Given the relatively short bursting radius of the 20mm ammunition compared to the ranges required for effectiveness, it is imperative that the weapon system, to include the firer, be able to accurately deliver the projectile and have the warhead detonate precisely where intended. Accuracy, precision of detonation and lethal effects are the cornerstones of this weapon program, and another topic of concern.

> The lethal radius of HEAB munitions should be improved and demonstrated in Government tests [SER 2000].

For defilade targets, the OICW primary HEAB ammunition is required to provide a per shot P(i) of 0.35 against an individual threat soldier protected with body armor and in a defilade position to 500 meters.

> To accomplish missions and survive in conflicts beyond 2007, the focus of the OICW must be on lethality against defilade targets at extended ranges. A P(i) of 0.35 is infinitely better than baseline systems because current systems have no chance of engaging defilade targets (e.g., targets gone to ground, in foxholes, in trenches, behind trees and walls, or on rooftops) [ORD 2000].

In addition to the factors related to OICW error for stationary exposed point targets, additional sources of error affected the conduct of the defilade target tests. Increased error resulted in the inclusion of a moving target, the increased difficulty in accurately ranging to and engaging a target at the exact time and location where the target goes into a defilade.

The process of range estimation provides the largest source of error in target engagement. For defilade targets during the ATD test firings, gunners produced a range estimating error standard deviation of 15.3 meters alone at a range of 300 meters to the target. Given the accumulation of additional error such as soldier aim error, round to round dispersion, round detonation variability and variability in lethal effect of each round, there is an apparent large variability in target effects for the ammunition.

Error in relation to the bursting radius of 20mm munitions to the target is a significant factor in P(i). Determining range of defilade targets is more difficult than for stationary exposed targets due to tracking target movement and estimating the location of the target while in defilade. The defilade target range error was more than twice the stationary exposed target range error. Demonstrated range estimation error shows an integration issue between the user and the component. Given these factors, a burst radius of approximately three meters, and the corresponding relative large amount of variability in burst location, it is likely the combat and material developers will have to address both capability of the weapon and ammunition as well as address methods of target engagement to attain the threshold requirement. Here, technology has not been matured to overcome difficulty in accurately determining range to target when that target is moving, or allow for a virtual point of reference to assist the soldier in determining where the target last appeared. According to the ATEC System Evaluation Report, a possibility for improving range estimation error is the inclusion of a laser beam stabilizing and cuing module added to the TA/FCS. This module would detect movement and place an aiming aid around the target. This coupled with a beam steering device would keep the laser centered on the target providing continuous range updates to the TA/FCS.

5. Problem Four--Target Acquisition

The OICW target acquisition/fire control system (TA/FCS) is intended to provide the infantryman with the means to perform all three aspects of target acquisition through a single, integrated subsystem and at greater ranges than current methods. Target acquisition includes detection, recognition and identification of a potential target. Detection is the discovery of an object that has military significance. Recognition is the ability to determine if the detected target poses a threat. Identification is the determination of the specific configuration (e.g., unprotected troops in the open) of the target. Identification assists the gunner in determining the effective employment of weapons.

The target acquisition/fire control system is required to be a single, compact, integrated day/night eye-safe device capable of operations in all environments. The OICW TA/FCS is designed to allow a soldier-operated full solution fire control system that ensures the firer can maximize system effectiveness from zero to 1,100 meters. The goal is to allow the individual soldier to detect and engage stationary, moving and defilade (point and area) targets on the battlefield during day, night and limited visibility conditions.

The fire control is required to include range finding data, allow for manual indexation of range based on laser rangefinder data, ballistic solution with inputs for cant, air pressure and temperature, reticules to assist the firer in holding to an adjusted aim point based on ballistic solution, an electronic compass and inclinometer, combat identification capability, training laser engagement system, infrared laser aiming and illuminator/pointer, thermal sighting capability, daylight television and direct view optics. The challenge for the developers is to maintain weight requirements while meeting the many fire control functionality requirements.

There was no thermal sight available for testing in the ATD phase. However, with similar weapon sights for the modular weapons system (MWS) show promise for incorporating a thermal sight into the FCS [SER 2000]. In clear air at 1100 meters, a medium thermal weapon sight (MWTS) demonstrated requisite capability for meeting OICW ORD requirements.

D. LESSONS LEARNED

The Air Force Research Laboratory, a leader in the adoption of characterizing technology for inclusion in programs, considers TRL 6 an acceptable risk for a weapon system entering the program definition stage, the point at which DOD launches its weapon programs, and TRL 7 an acceptable risk for the engineering and manufacturing development stage. This is an important distinction because leading commercial firms launch a new product later than DOD, after technology development is complete. They refer to this point as the beginning of product development, the point at which they commit to developing and manufacturing the product. Typically, the GAO report contends, technology is still being developed when DoD weapon system programs are launched--the time at which a weapon system is far enough along to compare to a commercial product development is likely to be at or after the start of engineering and manufacturing development.

To contrast, the GAO reviewed commercial and DOD experiences in incorporating different technologies into new product and weapon system designs. The technologies were drawn from commercial firms recognized for their success in developing technically advanced products more quickly than the products' predecessors and several DOD weapon system programs that incorporated advanced technologies, including some that did not encounter problems and some that did. A difference in the product or weapon success depended, in part, on an assessment of the maturity of the technologies at the point they were included in product development. Hughes Space and Communications demonstrated a successful case with the development and launch of the HS-702 satellite in 1999. *Hughes' approach was not to accelerate technology development but to shorten product development by maturing the technology first.*

Hughes began developing solar cell technology that had the potential of greatly increasing the electrical power on satellites. By 1985, a Hughes laboratory had demonstrated the technology by ground testing prototypes. Hughes was not satisfied that the supporting technology (materials, reactors, and test equipment) was mature enough to sustain development and production of the new technology on a satellite. This infrastructure was considered critical to meeting the cost and schedule requirements of a product. *As a result, Hughes did not transition the technology to a product, but kept it in a research environment, separate from cost and schedule pressures.* In the early 1990s, Hughes launched a new satellite program-- the HS-702-- that would use the solar cell technology to beat the competition. After a laboratory demonstration in 1993, Hughes successfully used the new technology on an existing version of a satellite before it began product development on the HS-702 satellite. By 1994, it had determined that the business base was available to sustain development and production of the new satellite. *Hughes waited 10 years for the demonstrated technology to meet the requirements.* The new technology took 10 years to mature enough for product readiness [SpaceRef 2001, GAO 1999].

E. SUMMARY

The prototype demonstration of the key performance parameters of the OICW during the ATD shows at least three of the KPPs were not met. These data assist in demonstrating the relative technology maturity and the possible linkage between inadequate technology maturity and increased program risk.

The goal of the ATD was to mature technology for inclusion in the weapon system and eliminate unattainable technologies in the early stages of development. In the actual conduct of the ATD, the system failed to achieve its 19.9 pound loaded weight requirement by half of a pound. Since the weapons tested were prototypes and with likely physical and functional changes, firing position testing did not occur. However, a human factors questionnaire demonstrated possible issues involving magazine location coupled with weight and awkwardness. The third parameter of range and lethality demonstrated the lethal radius (where the P(i) is .50) did not meet requirements for point, exposed targets. Additionally, during the ATD test firings, gunners produced a range estimating error standard deviation of 15.3 meters at a range of 300 meters to defilade targets. Although there was no thermal sight available for testing in the ATD phase, tests of similar weapon sights for the modular weapons system (MWS) have shown promise for incorporating a thermal sight into the OICW.

> The major risk areas identified from the ATD are: 1) maintaining performance in each of its three modes in a fully integrated sight, 2) achieving performance within weight requirements for an integrated sight, and 3) the ruggedness of an integrated unit [SER 2000].

Despite these apparent shortcomings, the milestone decision authority (MDA) allowed the program to transition to an acquisition program. However, as a risk mitigation effort, the program was directed to transition into a program and risk reduction (PDRR) phase rather than the planned engineering and manufacturing development (EMD). The key performance parameters of weight, firing positions, point exposed stationary and defilade target probability of incapacitation and system ruggedness were either not met or not evaluated.

Incorporation of advanced technologies before they are mature has been a major source of cost increases, schedule delays, and performance problems on weapon systems [GAO 1999]. In the succeeding chapter, I will analyze the effectiveness of the ATD in developing the OICW for transition and lessons learned that are applicable to this study.

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IV. FINDINGS

A. ANALYSIS/LESSONS LEARNED

> Leading commercial firms have changed their practices for developing products and have achieved the kinds of results DOD seeks. Maturing new technology before it is included in products is one of the main determinants of these firms' successes. This practice holds promise for DOD, for immature technologies have been a main source of problems on weapon systems [GAO 1999].

The goal of the ATD was to mature technology for inclusion in weapon systems and eliminate unattainable technologies in the early stages of development. The ATD key performance parameters of weight, firing positions, and point exposed stationary and defilade target probability of incapacitation were either not met or not evaluated. However, the milestone decision authority (MDA) allowed the program to transition to an acquisition program. Why would a program be given the green light to proceed when so many of the key parameters of the system did not meet the criteria for transition? The probable answer is linked with the way technology development mechanisms are funded in the DoD.

> The DoD is likely to move technologies to product development programs before they are mature. Science and technology efforts, which traditionally operate within fixed budget levels, do not necessarily have the funds to mature technology to the higher TRLs. Programs are more able to command the large budgets necessary for reaching these levels. The pressures exerted on new programs to offer unique performance at low cost encourage acceptance of unproven technologies [GAO 1999].

The transition of the OICW to an acquisition program was not an act of wholesale disregard for best practices in technology development. With the test and evaluation community wanting to see greater adherence to exit criteria, the transition was likely an acknowledgement that the money and resources required to further develop the required technology lay within the Program Office and not the science and technology development mechanisms. An acquisition advisory board recommended the OICW proceed to PDRR with concurrence of the Army Staff. With the results of the ATD failing to meet the exit criteria, this approval to proceed demonstrates the inconsistency in adhering to established doctrine for technology development. However, with the increased program management funding and manpower that can be brought to bear on developing a weapon comes the increased risk of maturing key technologies concurrent with managing an acquisition program. Each of the four KPPs that were not tested or did not pass ATD exit criteria increased technological risk to the Program Office. These increased risks allow the possibility of lengthened development times, increased costs and potential program termination in the current acquisition culture.

1. Problem One—Weight

The threshold weight requirement for the OICW is less than 14 pounds with all stated capabilities and when fully loaded with prescribed ammunition. However, the objective weight, the weight the combat developer would prefer the system weigh, is less than 10 pounds [ORD 2000]. For the ATD, the system failed to achieve its 19.9 pound loaded weight requirement by half of a pound, representing an approximately 2.5% shortfall, but without all of the requisite capabilities. The estimated 21.08-pound weight is a better representation of the objective system, given the state-of-the-art of the systems that were omitted from the ATD system. This increases the overweight percentage to just under 6% of the ATD goal, is over 50% greater than the ORD threshold weight of 14 pounds and more than 100% greater than the objective weight.

With such a disparity between the threshold and prototype weight, there will have to be significant materiel and engineering changes to the weapon, or relaxation of the requirement. If the requirement is inflexible, we can assess the TRL for weight as being in the breadboard configuration for testing and thereby falling into TRL 5.

TRL	Technological Characteristics
9	Actual system “flight proven” through successful mission operations
8	Actual system completed and “flight qualified” through test and demonstration
7	System prototype demonstration in an operational environment
6	System/subsystem modes or prototype demonstration in a relevant environment
5	Component and/or breadboard validation in a relevant environment
4	Component and/or breadboard validation in a laboratory environment
3	Analytical and experimental critical function and/or characteristic proof of concept
2	Formulation of technology or application
1	Basic principles observed and reported

Table 4-1, Weight TRL

As noted in chapter III, the Air Force Research Laboratory considers TRL 6 an acceptable risk for a weapon system entering the program definition stage, and TRL 7 an acceptable risk for the engineering and manufacturing development stage. Ideally, technology should be at a maturity level of TRL 6 before proceeding to PDRR.

Not meeting the exit criteria for weight will create a significant technological challenge for the Program Office. Because the prototypes in the ATD were manufactured with exotic materials (beryllium fire control housing, titanium sleeves for the barrels and composite materials in the receiver) in an attempt to achieve the ATD weight goal, the Program Office and contractor have few, if any, alternatives to further reduce system weight with the current technology available. This will require the Program Office to commit more funding to the development of alternative materials or achieve relief from the requirements of the combat developer and user.

Since the user is the infantryman and the amount of equipment a soldier can be expected to carry while remaining combat-effective is limited, the Program Office will likely have to expend significant resources and much effort to influence the Combat Developer to make some difficult trade-offs for any compromise from the threshold weight requirement. Additionally, with continued developmental testing addressing the weight, will continue to generate test reports that reflect failures to meet weight related technical performance measures. In today's acquisition culture, even developmental testing conducted by the Program Office advertises progress, or lack thereof, in attaining key performance parameters (KPPs) to the acquisition and political communities. These test results typically create negative perceptions that have consequences impacting funding availability and may jeopardize the entire program. By accepting a relatively low TRL for weight using technologically advanced and costly materials, the Program Office is placed in a difficult situation of having to develop cutting edge technology to the point where it can be integrated into a weapon system economically.

2. Problem Two--Firing Positions

Advanced technology demonstration testing did not address the firing position parameter. Since the ATD was a test of prototypes, a finding would likely be moot since the ATD weapon may not be physically representative of the production weapon, although ATD data on differing firing positions would have provided valuable information regarding the design demonstrated. More importantly, data on firing position effectiveness would have provided significant insight regarding the weapon design maturity and would have allowed a distinction between a breadboard platform, TRL 5, and a brassboard platform, TRL 6.

Despite the prototype designation of the ATD OICW, the results of the human factors questionnaire administered to the test participants demonstrate that factors of magazine location, coupled with weight and awkwardness of the weapon frame, infer firing from positions other than kneeling supported may be compromised. Aggravating factors in maintaining a steady hold in realistic conditions can increase errors in engaging targets, reducing weapon system suitability and negatively impacting soldier combat effectiveness. Although the ATD did tacitly address the issue of differing firing positions, it is important to note what the ATD did not measure—what the OICW configuration should conform to in terms of soldier firing position.

The weapon must provide the soldier with firepower in a wide range of mission and terrain combinations. The use of varying firing positions is critically important when conducting dismounted maneuver. A soldier can be expected to fight from any terrain and firing positions can vary with the types of terrain encountered, however, there are four major positions: standing kneeling, sitting and prone—with standing and kneeling most likely to be used while in enemy contact.

The weight of the prototype weapon will adversely affect the ability of the soldier to maintain a steady hold in order to range to, and fire on the target. With an awkward hold and weight exceeding 19 pounds, a soldier firing in an urbanized environment where speed of action and limited use of supporting materials require an offhand hold (no additional support of the weapon weight) will have difficulty in maintaining consistent, steady holds. Whether in the standing or kneeling position, the soldier must support the weapon using his own skeletal and muscle structure. The time to reduce weapon wobble must be long enough to orient the weapon, aim, range then fire. It is unlikely that any soldier would be able to maintain such a hold for more than a few seconds. Certainly, expert marksmen do have the capability to hold a heavy, match grade rifle to reduce weapon wobble and attain accurate fires. The difference is that the target shooter can assume a stance where the weapon can be place very near the shooter's center of gravity. For the prototype OICW, the firer must extend both arms out further from the body's center of gravity. This act requires more use of muscle to maintain a steady hold rather than relying upon skeletal structure. The result is a reduced ability to control muzzle wobble and reduced time to maintain that steady hold. While in contact, however, the soldier must contend with more than simply holding the weapon steady. A soldier must also move in addition to shooting, communicating and sustaining for success in combat.

The soldier's weapon must be designed to permit quick movement and allow quick shouldering or bringing the weapon to bear on the enemy to provide precision point fires or suppression of an area. When the soldier must execute individual movement techniques to evade acquisition or effect bounding maneuver, an awkward weapon may adversely affect his ability to conduct such movements, quickly with ease of action. In this instance, a soldier operating as part of a larger element-- fire team or squad-- may have to roll from a prone position to move to the flank of his location to execute a quick rush to the next firing position. This act is to avoid the possibility of being engaged by an enemy who has acquired the soldier's position and is prepared to fire on that position once the soldier has exposed himself to move forward. The soldier will roll to the flank or to the rear of a hasty position to have the best chance of moving undetected or at least buy enough time to stand, rush and assume another prone firing position before the enemy can re-acquire and engage.

Of particular concern among these conditions would be an assault on terrain with little in the way of relief or undulations in the terrain to provide natural cover (physical protection from projectiles) and concealment (camouflage). Given a scenario of an assault against a prepared fighting position in desert terrain, the height of the prototype OICW (the distance from the inserted magazine bottom to the top of the TA/FCS) would place the firer's head dangerously high while firing from a prone position in an open area, prone firing position. What the combat developer requires, and the issue the Program Office must contend with, is how the components of the system may be reduced in height to allow a soldier to hold, aim, fire and adjust rapid subsequent shots while maintaining a very low silhouette in open terrain. Attaining such a goal will likely require a significant engineering redesign in the form of reducing the TA/FCS height, minimizing the distance in the axis between the bores of the two component weapons, minimizing the size of recoil dampening mechanisms and decreasing the height or the relative positions of the magazines. A major engineering redesign of the OICW means that the ATD design was not representative of that needed to meet the program objectives. By definition, the ATD system was a breadboard representation of the objective system.

Characterizing the physical configuration of the OICW in terms of a TRL demonstrates a maturity of 6. This is misleading by the fact, however, that only a single firing position was used in the testing. Given the indications from the Human Factors questionnaires, a TRL of 5 might be just as appropriate.

TRL	Technological Characteristics
9	Actual system “flight proven” through successful mission operations
8	Actual system completed and “flight qualified” through test and demonstration
7	System prototype demonstration in an operational environment
6	System/subsystem modes or prototype demonstration in a relevant environment
5	Component and/or breadboard validation in a relevant environment
4	Component and/or breadboard validation in a laboratory environment
3	Analytical and experimental critical function and/or characteristic proof of concept
2	Formulation of technology or application
1	Basic principles observed and reported

Table 4-2, Firing position (physical configuration) TRL

With the ATD not fully addressing the concern of firing positions, testing in a relevant environment in itself will not validate the design aspects of the weapon based on the available technology. This fit between demonstration of technology to support a compact, quick-handling weapon and the desire to transition to EMD characterizes the ATD as not sufficient to successfully transition the weapon to an acquisition program.

This will prove to be a very challenging aspect of the weapon system for the Program Office. As with the weight issue, there is likely to be little relief in the requirements for firing positions. The Program Office will have the task of carefully optimizing strength of materials to weight and requiring significant engineering changes to current design, or possibly a total redesign, to attain threshold requirements.

3. Problem Three--Range/Lethality

The OICW ATD did not meet the criteria for lethality for point exposed and defilade targets. This issue has three main components for the Program Office to address: Munitions technology development, accuracy improvement and tradeoff analyses.

The burst radius of the 20mm round did not meet criteria for the ATD. The rounds used during the ATD used fusing technology using micro-mechanical devices to determine arming and detonation distances. In order to increase the effectiveness of the ammunition, changes in explosive and fusing will have to be considered. This will increase the time required to develop the weapon system to meet requirements in the ORD. With the ammunition developed and the developmental nature of the demonstration, the lethality component of the OICW is characterized by a maturity of TRL of 3.

TRL	Technological Characteristics
9	Actual system "flight proven" through successful mission operations
8	Actual system completed and "flight qualified" through test and demonstration
7	System prototype demonstration in an operational environment
6	System/subsystem modes or prototype demonstration in a relevant environment
5	Component and/or breadboard validation in a relevant environment
4	Component and/or breadboard validation in a laboratory environment
3	Analytical and experimental critical function and/or characteristic proof of concept
2	Formulation of technology or application
1	Basic principles observed and reported

Table 4-3, 20mm ammunition (lethality) TRL

During the ATD, soldiers firing the OICW at defilade targets demonstrated a sizeable margin of error in aiming the weapon, significantly reducing the P(h) and the corresponding combat effectiveness of the 20mm portion of the weapon system. The margin of error was attributed to the difficulty in estimating a range to a target that was in a defilade position behind cover. The inability to directly aim the laser at the target meant that the firer lacks a reference point to gain ranging information from the laser. In these situations, the firer must make a best guess as to where to place the laser aiming light for more accurate determination of range. However, this assumes the target is in a position with few or no reference points in which to laser-range a target location. If the environment were changed to an urban area, and the target within a room with a window, the firer would have a reference point with which to aim and range. The effect on the

Program Office will be to develop courses of action to address the accuracy issue. Courses of action can range from added functionality to assist the firer in maintaining a steady hold on the target (bipod or laser steering) to weight reduction and enhancing the weapon's balance/configuration to assist in a more stable hold. With the prototypes weighing almost 20 pounds and firers having to assume a difficult weapon hold, the firer's ability to reduce weapon "muzzle wobble" is diminished.

Lethality is primary to the effectiveness of the weapon, but also may allow requirements tradeoff from the combat developer. The results of the ATD for the accuracy issue may require the Program Office to manage the development of technology to increase the effectiveness of the 20mm munitions. This could have a significant effect on the cost and schedule of the program if new technologies are required to replace existing ammunition fusing and explosive mechanisms. An alternative is to influence the combat developer to trade-off the requirement for lethality, range, or a combination of both. In either case, the Program Office will have to expend additional resources to manage the technology development to allow a greater bursting radius of the 20mm ammunition or to provide supporting data to support a relaxation of the requirement. The ATD provided no indication regarding the ability to mature the 20mm technology sufficiently to meet the ORD requirements. Failure to meet the requirement or to provide convincing data to support relaxation of the existing requirement, adds significant technological risk to the program and, in the worst case, could result in the system being deemed ineffective which typically results in termination of the program.

4. Problem Four--Target Acquisition

During the ATD, the OICW possessed only the laser rangefinder, direct view optics, fire control and reticule. The ATD prototypes did not satisfy all of the user's requirements [SER 2000]. There was no thermal sight available for testing in the ATD phase; however, a previously tested medium thermal weapon sight (MWTS) demonstrated requisite capability for meeting OICW ORD requirements. There was no exit criterion for a thermal sight and for much of the ORD required functionality of the TA/FCS. With a prototype TA/FCS having only the laser rangefinder, direct view optics, fire control and reticule portion of functionality, the Program Office incurs the increased burden of managing the inclusion of thermal imaging, a training laser, inclinometer, daylight television, combat identification system, compass and laser illuminator/pointer into the sight. Addition of the required functions to the TA/FCS is likely to increase weight. The impact on the Program Office is increased performance risk in managing the reduction of system weight, and the added required functionality of the TA/FCS. With the TA/FCS having only three of the required ten functions, it can be characterized as breadboard. The three functions demonstrated are characterized by a maturity of TRL 5, but the remaining functions fall in TRL 3, as they were not incorporated into the functioning ATD system.

TRL	Technological Characteristics
9	Actual system "flight proven" through successful mission operations
8	Actual system completed and "flight qualified" through test and demonstration
7	System prototype demonstration in an operational environment
6	System/subsystem modes or prototype demonstration in a relevant environment
5	Component and/or breadboard validation in a relevant environment
4	Component and/or breadboard validation in a laboratory environment
3	Analytical and experimental critical function and/or characteristic proof of concept
2	Formulation of technology or application
1	Basic principles observed and reported

Table 4-4, Target acquisition TRL

B. SUMMARY

None of the technologies supporting key performance parameters included in the OICW ATD were developed to a maturity level sufficient to reduce risk to an acceptable level for the Program Manager. OICW prototype system weight for the ATD was 19 pounds—with the use of lightweight metals and composites. The prototype weight represents the current state-of-the-art in lightweight materials, forcing the Program to achieve the weight requirement in time for a 2009 fielding—the result is increased performance and cost risk to identify lightweight materials and the processes to economically produce weapon components from those materials. The heavy weight of the OICW relative to similar weapons, and a configuration that does not afford a steady hold, negatively affect the soldier's ability to aim and range to a target. In addition, heavier weapons have a negative impact on soldier endurance affecting combat mission performance. The technology to support miniaturization of components and a configuration to support survivability was not mature for the ATD—the result is increased performance risk for the Program. The lethality of the OICW primary ammunition did not meet exit criteria. The effort to increase the effectiveness of the 20mm round is likely to involve application of new technology to increase the payload of explosive to increase effectiveness. The result is likely performance and schedule risk in managing the development and integration of new technologies.

The likely outcome of the OICW program will be an ultimately successful system that, through iterative refinements in pre- and post-production, meets possibly relaxed requirements. But given the immature technologies noted in the ATD, these successes will be at the expense of time to field the system and increased development and life cycle costs. The adoption of immature technology in the OICW program is consistent with historical examples of weapon system acquisition programs.

> (Service) programs allowed more technology development to continue into product development. Consequently, the programs proceeded with much less knowledge--and thus more risk—about required technologies, design capability, and producibility. The programs' discovery process persisted much longer, even after the start of production. Turbulence in program outcomes--in the form of production problems and associated cost and schedule increases—was the predictable consequence as the transition to production was made [GAO 1998].

According to Department of Defense Instruction 5000.2, ATDs shall be used to demonstrate the maturity and potential of advanced technologies for enhanced military operational capability or cost effectiveness. Technology must have been demonstrated in a relevant environment to be considered mature enough to use for product development in systems integration. If technology is not mature, the service component is required to use an alternative technology that is mature and that can meet the user's needs [DoDI 5000.2 (2001)]. However, as the data demonstrates, the OICW program now must integrate technologies that were not matured, and in numerous cases, not demonstrated, for inclusion in the system.

> For those technologies with the most promise for application to weapon systems, component science and technology executives must be responsible for maturing technology readiness level that puts the receiving MDA at low risk for systems integration and acceptable to the cognizant MDA, or until the MDA is no longer considering that technology [DoDI 5000.2 2001].

A possible answer to the question of why the OICW transitioned to an acquisition program is funding. Members of the acquisition team (material and combat developers and contractors) are incentivized to transition the program to an acquisition program as rapidly as possible. An established Program Office is more likely to obtain the funding necessary for developing technologies more quickly than science and technology efforts. The risk with regard to the program manager is the fairly rigid requirement to meet cost, performance and schedule goals managing the development of technology that may not conform to the timelines established. The pressures exerted on new programs to offer performance to meet requirements encourage acceptance of unproven technologies.

> Although the intent of ATDs is to help speed the introduction of advanced technologies needed to develop future systems and allow experimentation with technology-driven operational issues, acquisition programs are likely to move technologies to product development programs before they are mature [GAO 1999].

The demonstrated readiness levels for the key technologies included in the OICW did not meet the intent of Defense Department and Army requirements for technology maturation.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The purpose of this research is to examine the efficacy of the OICW's ATD in preparing the system for transition to an acquisition program. The analysis in chapter IV provided insight into the effectiveness of the OICW ATD approach to developing technologically advanced weapon systems and transition to program management.

> The ATD process did not produce a system design incorporating a path leading to the fulfillment of all KPPs and other requirements, most notably the preparation for the operating environment (reliability, ruggedization, maintenance, Soldier System weight, electronic battlefield) [Acquisition Strategy 2001].

1. Problem One—Weight

The OICW program transitioned too early for technology to support a dual munitions weapon weighing under the ORD required 14 pounds. The ascribed TRL of 5 for weight did not support the transition of the program from the ATD. The adoption of the program under these auspices will inculcate unacceptable performance and cost risks to the program, putting the program success in significant jeopardy.

2. Problem Two--Firing Positions

Significant design immaturity existed at the time of the OICW transfer from ATD to PDRR. Firing positions were not fully addressed during the ATD and the single firing position demonstrated using the prototype OICW was assessed at TRL 3.It is expected the fielded design of the weapon will differ significantly from the prototypes tested, requiring significant redesign. As there were indicators that the untested firing positions could be problematic with the ATD engineering design, a more realistic TRL of 3 could be assessed for the system, as it would be in the breadboard category. The original intent of the program was to mature key technologies to facilitate successful transition from ATD to EMD, but based on HFE questionnaires, the ATD design is expected to be awkward to hold and fire in many of the expected firing positions required by the infantryman. Unacceptable program risk is assumed by the OICW transition by not maturing the weapon design into a form and fit that better suited soldiers operating in a realistic environment.

3. Problem Three--Range/Lethality

The effectiveness of the 20mm OICW subsystem was not successfully demonstrated indicating the technology for properly ranging and engaging the ORD specified target set was not sufficiently mature to transition out of the ATD. During the ATD, soldiers firing the OICW at defilade targets demonstrated a sizeable margin of error in aiming the weapon. Additionally, the OICW ATD did not meet the criteria for lethality for point exposed and defilade targets. The transition of the program before the ammunition was developed to meet requirements will require the program to not only develop the weapon but also redesign the primary ammunition while developing the weapon itself. The TRL of 3 creates unacceptable cost and performance risk to the program.

4. Problem Four--Target Acquisition

The ATD was conducted without a fully functioning prototype TA/FCS and those associated Key Performance Parameters were not demonstrated, leaving the Program Office with an unknown risk of successful development or integration of the critical TA/FCS functions. The TA/FCS had the laser rangefinder, direct view optics, fire control and reticule portion of functionality. The additional functions of thermal imaging, a training laser, inclinometer, daylight television, combat identification, compass and laser illuminator/pointer were neither present nor tested in a breadboard design. This testing of components of the system placed the demonstrated functions of the TA/FCS at TRL 5, but the remaining functions would clearly fall in TRL 3 as they were not incorporated into the functioning ATD system. The effect on the Program Office is increased performance risk in managing the reduction of system weight with the added required functionality of the TA/FCS.

The ATD failed to demonstrate the technology to provide the PM and MDA with low risk technical solutions to attain threshold requirements. The data and analysis focused on the discrete technologies that in the spirit of the ATD would permit inclusion of the technology with the corresponding increase in capabilities without undue risk. What also must be considered is the effect of the integration of technologies to provide the required total system functions. The evaluation of the ATD was to characterize the effectiveness and suitability measures of the technology demonstrated within the framework of the exit criteria. What may be warranted is a characterization of the sum of technologies incorporated into the prototype system to render an overall measure of technical integration maturity. With TRLs for weight, firing positions, range/lethality and target acquisition of 5, 5, 3 and 3 respectively, the overall TRL for system integration would be at most 3 and there are significant risks associated with integration of functions that were not demonstrated or that were not successful in the ATD;

> …the integration of technologies at relatively high TRLs does not mean the system enjoys a high TRL. "If several technologies are at TRL 7, let's say, the system may only be at TRL 3 due to the complexities of integrating those technologies" [Snider 2001].

This characterization of the OICW ATD demonstrates the willingness to transition technology from the science and technology sector too early for that technology to allow functionality without undue risk. The result is that the onus then falls on the program manager and staff to manage not only the management of the program but also the development of sufficiently mature technologies to allow that program to be successful.

Given the results of the OICW ATD, OPM Small Arms decided that following a Simulation Based Acquisition (SBA) philosophy would provide the OICW PD&RR phase of the program the best chance of reaching the ORD requirements and provide sufficient data for the User to make intelligent trade-off decisions. This was the best course of action possible under the circumstances and the environment the PM must operate within to achieve success.

B. RECOMMENDATIONS

The Assistant Secretary of the Army for Acquisition, Logistics and Technology ASA (ALT) should require strict adherence to the use of technology readiness levels. The ATD process should use TRL 7 as a rigid requirement before technologies are to be incorporated into a weapon system before the system becomes an acquisition program.

The ASA (ALT) should enforce the proper characterization of technologies being considered and resist attempts by the acquisition community to adopt technology before it is matured so that it inculcates only low risk to a program. For example, 3M is developing a fuel cell technology for which they have built 15 prototypes for testing purposes at TRL 7 or higher. However, because the technology has not yet met all of the cost, schedule, and performance targets for product development, they have not allowed it to be included on a new product, despite demand from the marketplace [3M 2001, GAO 1999].

Department of the Army (DA) Pam 70-3, Research, Development, and Acquisition -- Army Acquisition Procedures section 2.7 -- Advanced Concept Technology Demonstrations (ACTDs) (Science and Technology Development, Demonstration, and Transition Information), Procedures paragraph, subparagraph 3—Advanced Technology Demonstration should be revised to read "not only speed maturation of technology, but ensure perspective technologies support the receiving program and constitute low risk in adoption." The result of adopting immature technology, as is the case with OICW, is that the OICW Program Manager must not only manage the integration of several technologies that make up the OICW, but must also manage the technology development itself. In order to maximize the probability of program success, the acquisition community should provide PMs with disciplined processes, readily available information, readiness standards, and authority to ensure technology is sufficiently mature for critical combat systems and products. This support would allow managers to safeguard product development from undue technology risks.

Revise Department of Defense Directive (DoDD) 5000.1; *The Defense Acquisition System*, section 4.2.1. -- *The Fundamental Role of the DoD Science and Technology (S&T) Program* to augment the responsibility of the science and technology developer to render technologically mature, low risk alternatives for inclusion in acquisition programs. This would allow promising technologies to remain in the S&T structure until a promising technology meets TRL 7 or 8 for inclusion into a prototype for testing. This would allow the Program Manager to focus on integration and program management. Some commercial firms establish a product development team that includes people from research and development, marketing, manufacturing, and other functions that transfer with the new technology and ensure it is integrated into the new product.

C. SUMMARY

In government acquisition, program managers are induced to incorporate immature technologies that offer significant performance gains. These pressures come from the user's perception of the threat, technologists that see the program as an opportunity to apply a new technology, and funding competition that rewards weapon systems with unique features. An environment that matures technology to achieve product readiness before it is constrained by the regulation of an acquisition program is required in this case. In successful programs, an environment provided by S&T organizations or a team of S&T and product developers, managed technologies to high readiness levels before they were included in an acquisition program. These organizations provided an environment more conducive to the ups and downs normally associated with the discovery process.

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SUGGESTED FURTHER STUDIES

The following areas should be investigated for potential benefit to the DoD:

The OICW program transitioned from a Science and Technology development program to an acquisition program before the criteria of the advanced technology demonstration could be attained. There is some evidence that the acquisition community pushes a program ahead in order to gain greater funding to accelerate technology maturation. An analysis of funding science and technology objectives in the armed services is required. Specifically, how science and technology efforts are funded to mature technology before incorporation into acquisition programs.

The prototype OICW fire control housing was manufactured from beryllium, a lightweight, yet toxic and expensive material. The system developers used this approach to reduce system weight and maintain strength and ruggedness. A study to evaluate and recommend potential alternatives to materials reducing weight and production costs is required to help the program move forward and meet cost and performance goals.

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APPENDIX A--QUESTIONS POSED

These questions were posed to members of the acquisition team involved with the OICW program in both the Government and commercial sector.

- Why did the OICW transition to an acquisition program even though ATD exit criteria were not met?
- What did the ATD prove?
- What matches were made between technology and requirements at program start?
- What are the factors of a 14-pound weight requirement?
- Who was on the test and evaluation IPT during the ATD?
- What recommendations do you have for the program to succeed?
- Were there emerging results the SER did not address that show promise for meeting KPPs?

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